eRHIC: a new collider to explore the femto-scale of protons and nuclei

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BROOKHAVEN NATIONAL LABORATORY

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

Young Researcher Symposium 2012

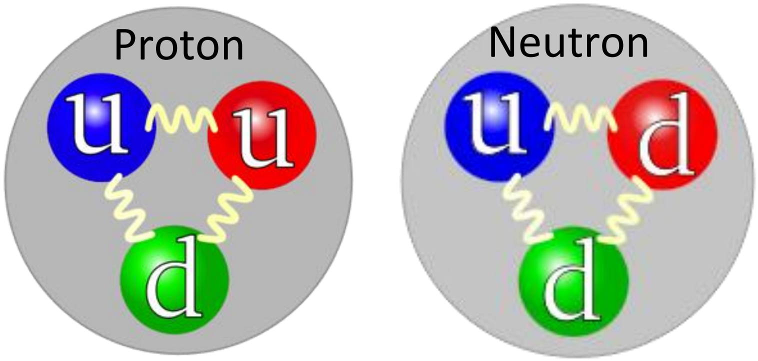
November 30th, 2012 Brookhaven National Laboratory

Overview

- Why we need to build a new Electron-Ion collider? Some physics motivations.
- Status of the project:
  - The collider
  - The new detector
- Silicon micro-vertex trackers.
- Conclusions.
- Other material on eRHIC.

Physics motivation 1: mass of nucleons

We know that Protons and Neutrons (Nucleons) contain **3** "main" quarks called valence quarks .....

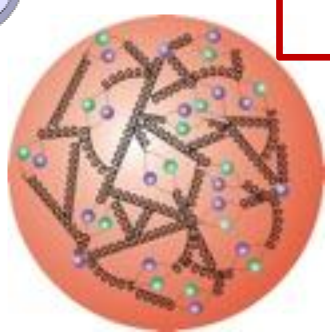


but looking inside more carefully there are also :

- Undefined number of gluons, that glue the quarks: the binding-energy
- Undefined number of couples, composed by quarks and antiquark: the sea quarks

Mass of nucleons are the same all of the time…
Number of valence quarks are the same, all of the time…

But valence quark mass
is only a small contribution of Nucleons mass !

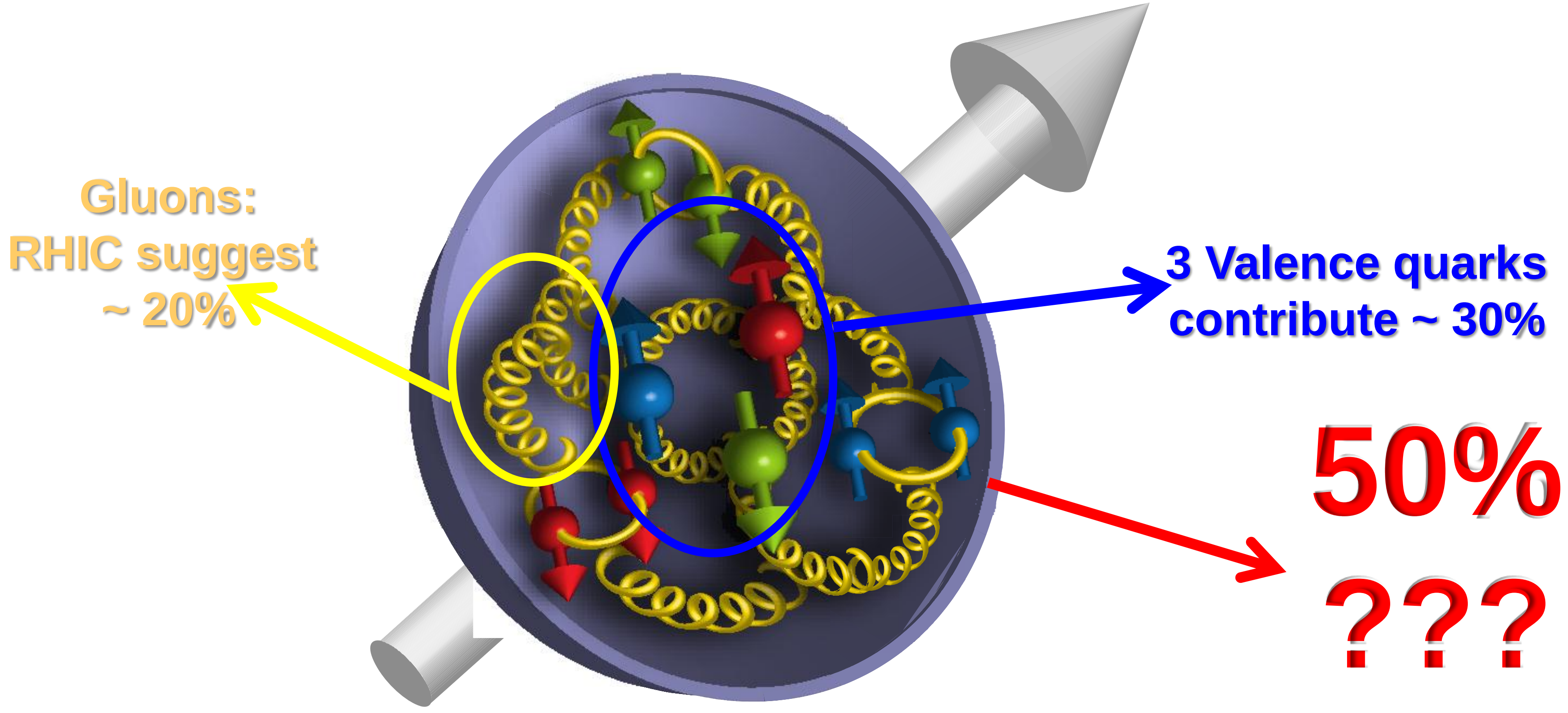


Binding-energy: ~10^9 eV
Quark-Masses: 10^6-10^7 eV

Mass is completely dominated by gluons !

Physics motivations 2: Spin of nucleons

Similar situation for the spin of nucleons :
we know the value but not the detailed contributions !



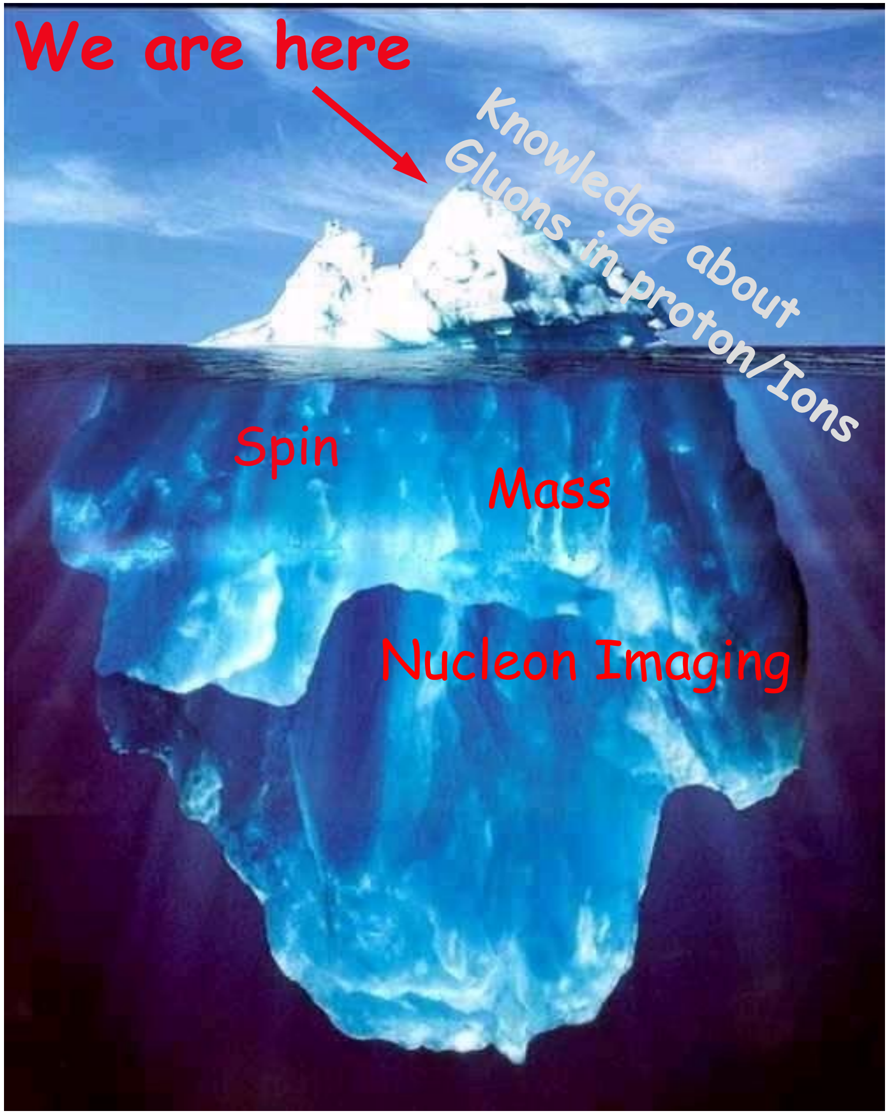
Physics Motivations

What we know now is only
The tip of the iceberg !

See Salvatore Fazio's talk and poster for more details.

To solve these puzzles we don't need to discover new exotic particles !

We need to know the properties of already discovered particles more intimately:
We need precision measurements



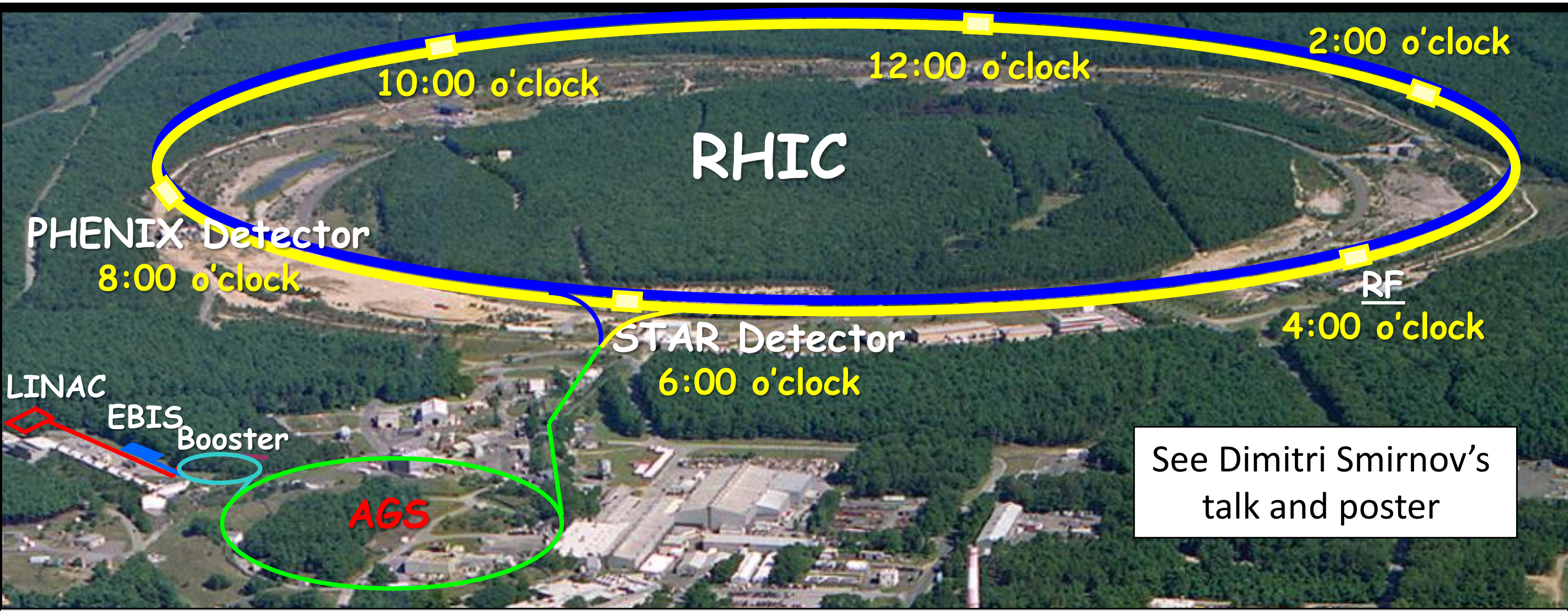
Physics motivations

A Electron/Ion collider is a precision measurement instrument because it uses an electron (a stable particle with no internal structure) as a probe, to explore the internal structures of complex objects such as nucleons and nuclei.

That's why it is like a "femtoscope" for Nucleons and Nuclei !

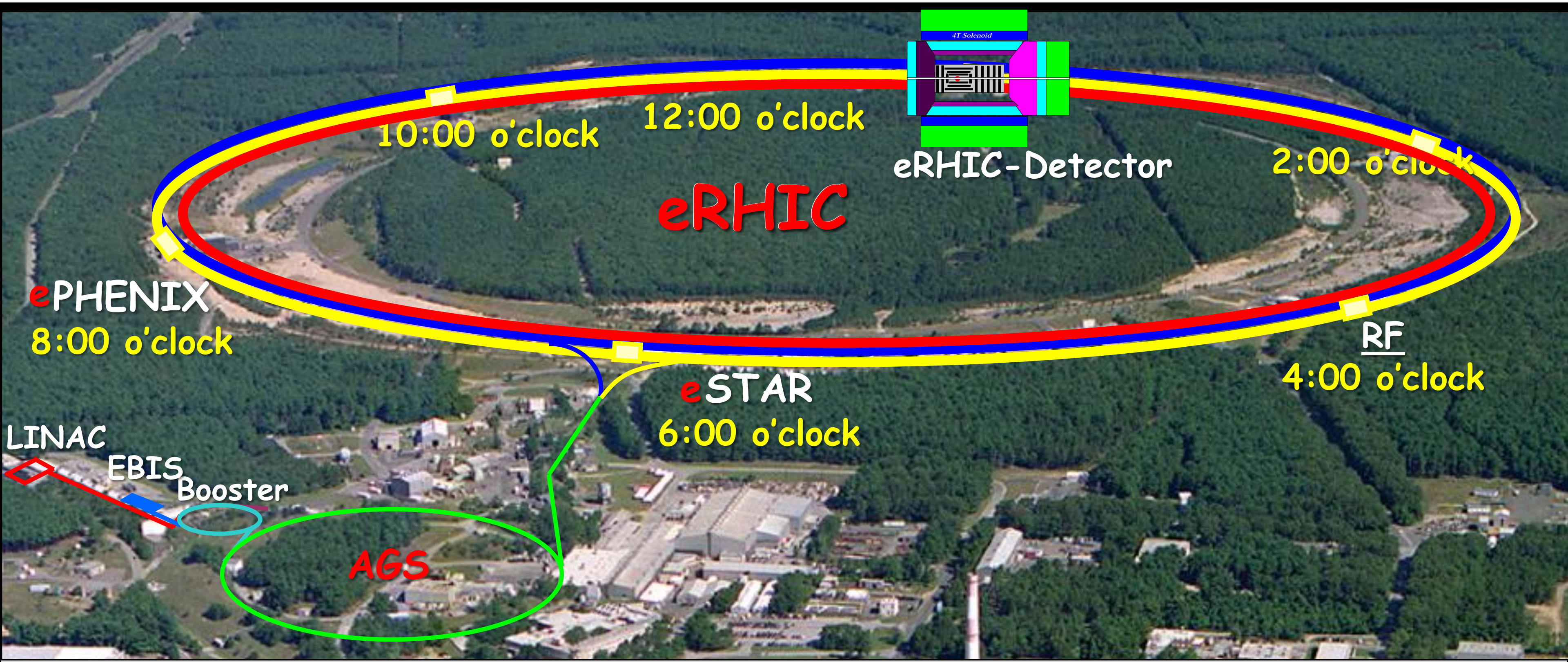
An Electon Ion collider like eRHIC
will be a quantum step to
provide the answers to many
of our questions on nucleons and nuclei

What we have now: RHIC
the first collider with polarized proton bunces

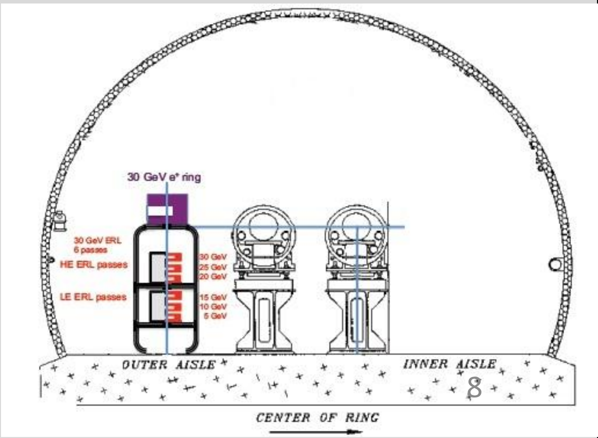


See Dimitri Smirnov's talk and poster

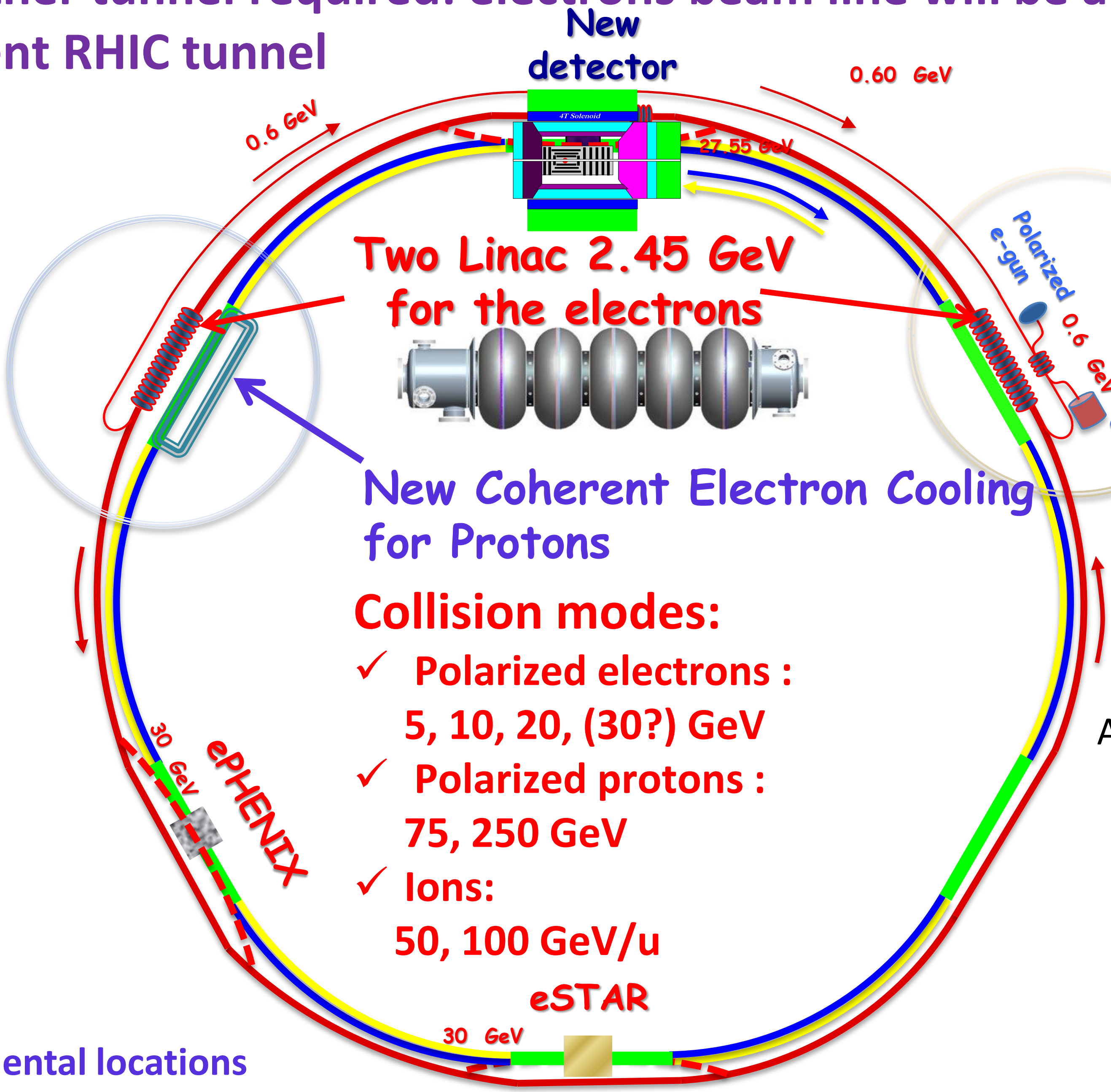
eRHIC: a new Electron Ion Collider



New electron ring
in the same tunnel



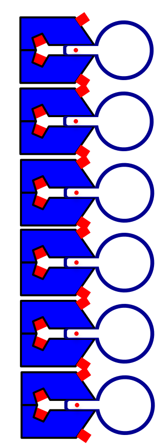
✓ No other tunnel required: electrons beam line will be added in the present RHIC tunnel



Collision modes:

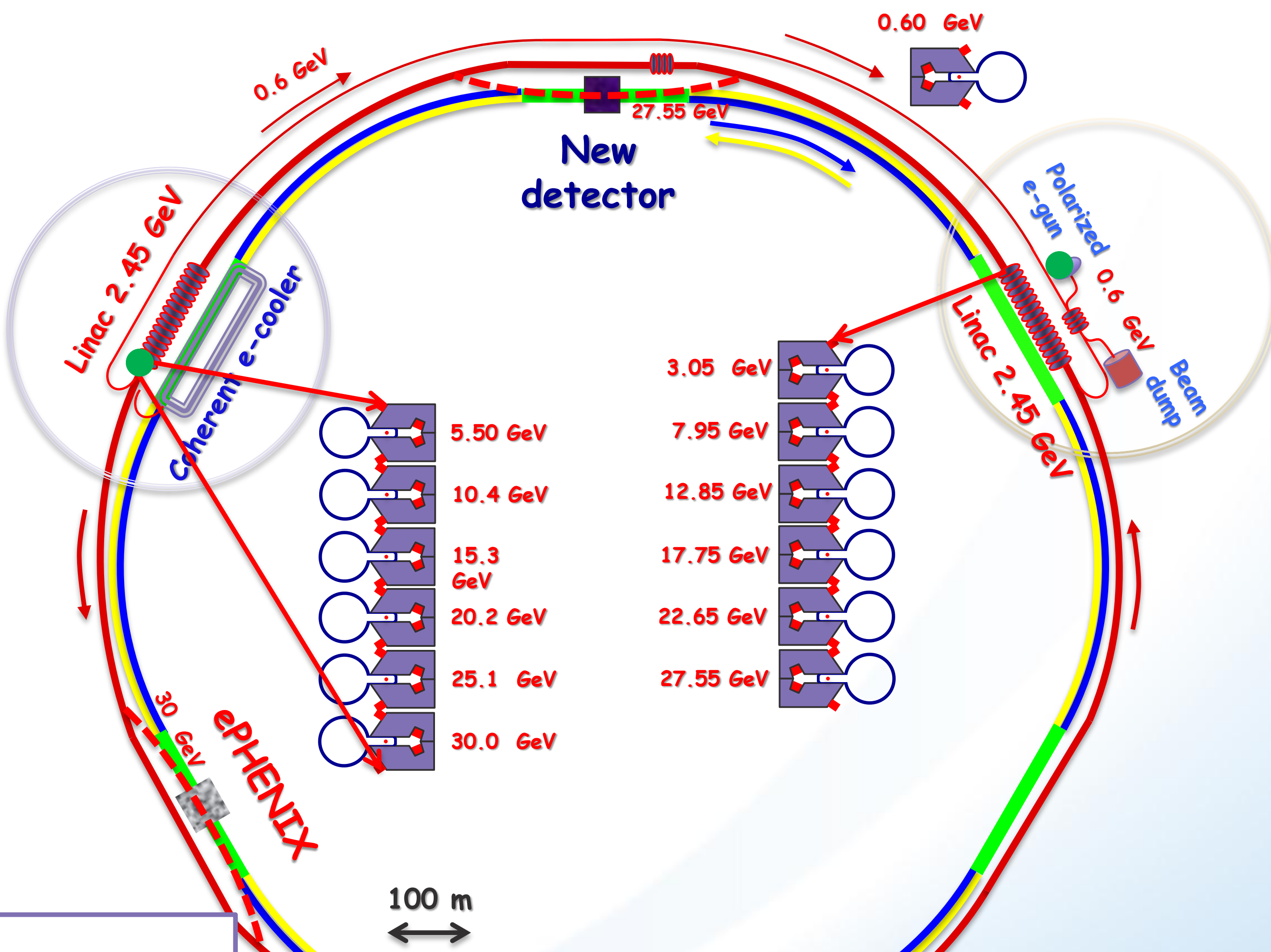
- ✓ Polarized electrons : 5, 10, 20, (30?) GeV
- ✓ Polarized protons : 75, 250 GeV
- ✓ Ions: 50, 100 GeV/u

Arcs design



✓ Up to 3 experimental locations

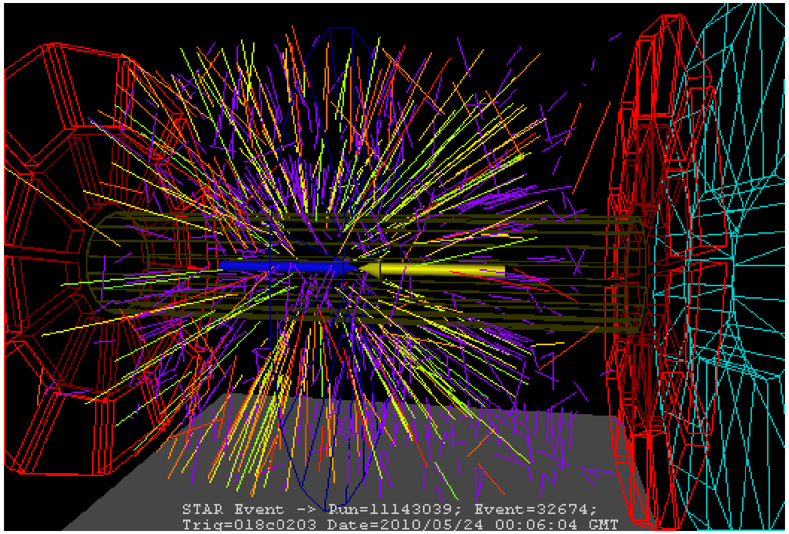
Electron beam evolution in eRHIC's ERL



From:
Vladimir Litvinenko (BNL)
Brookhaven Lecture
14th of November 2012

Animation is by N. Tsoupas

How does a detector recognize particles ?

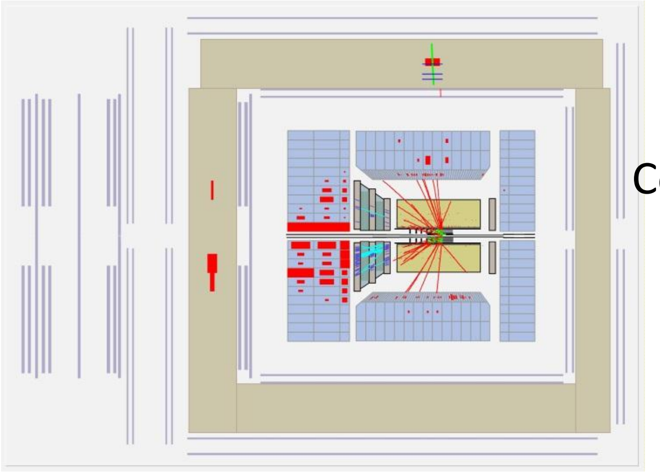


A detector look at the results of the collisions

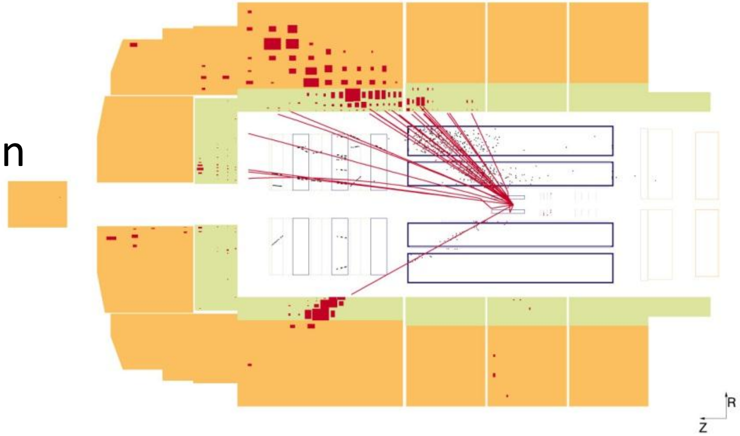
In order to design a detector it is important to do simulations in advance of the collision that have to be investigated !

See Liang Zheng's talk on Monte Carlo techniques

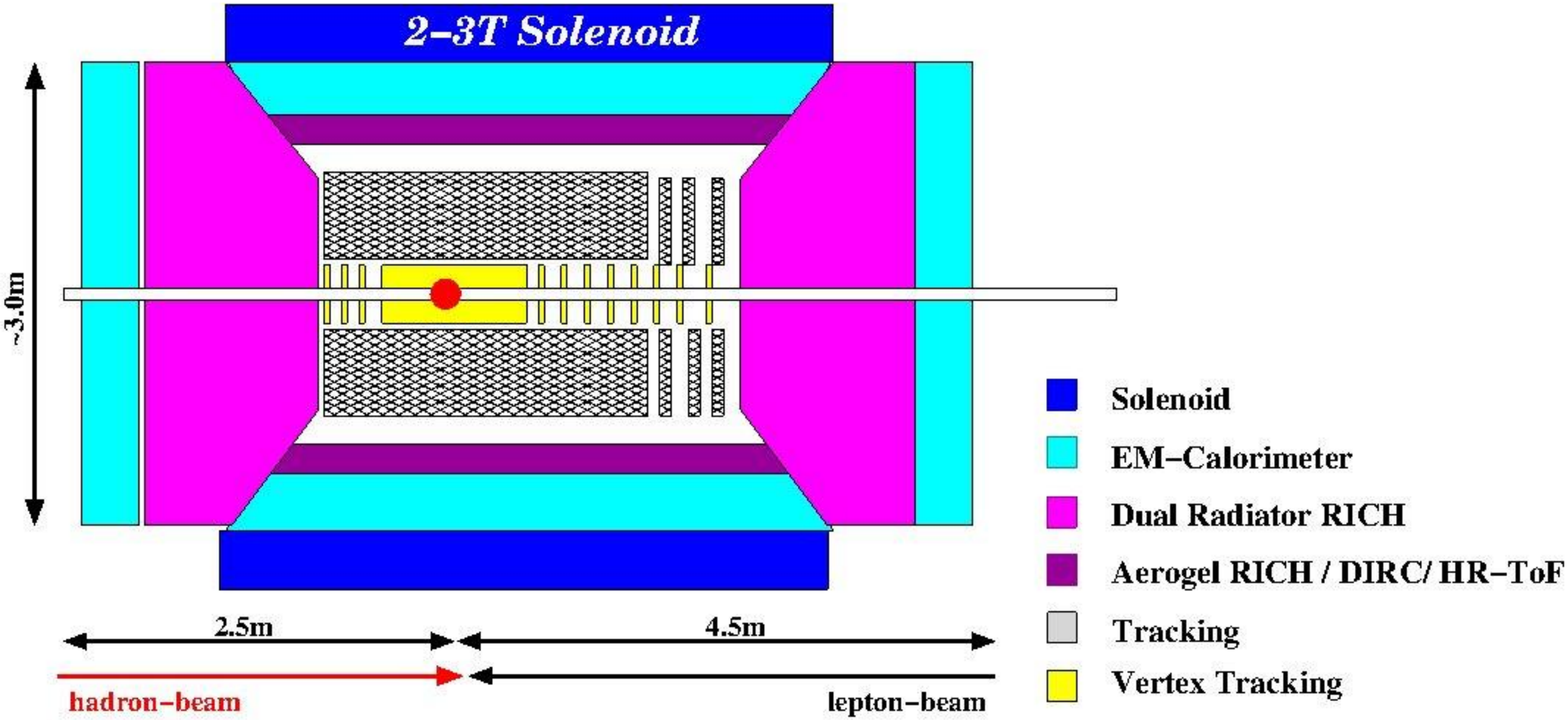
Collision in the Star detector



Collisions **electron proton** in
Zeus and H1
detectors
at the Hera collider



Overview of the New eRHIC Detector



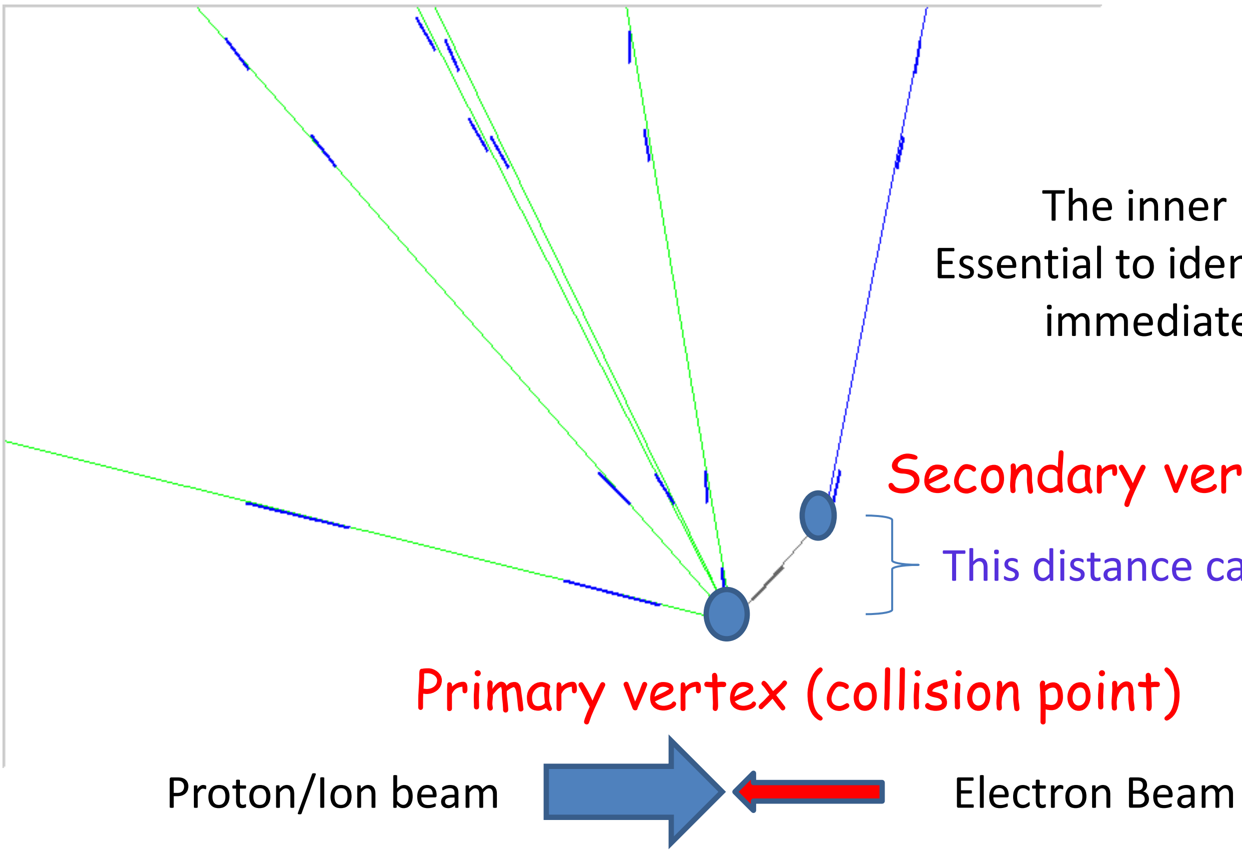
good PID (π,K,p and lepton) and vertex resolution (< 5μm)

tracking and calorimeter coverage the same → good momentum resolution, lepton PID

low material density → minimal multiple scattering and brems-strahlung

very forward electron and proton/neutron detection → maybe dipole spectrometers

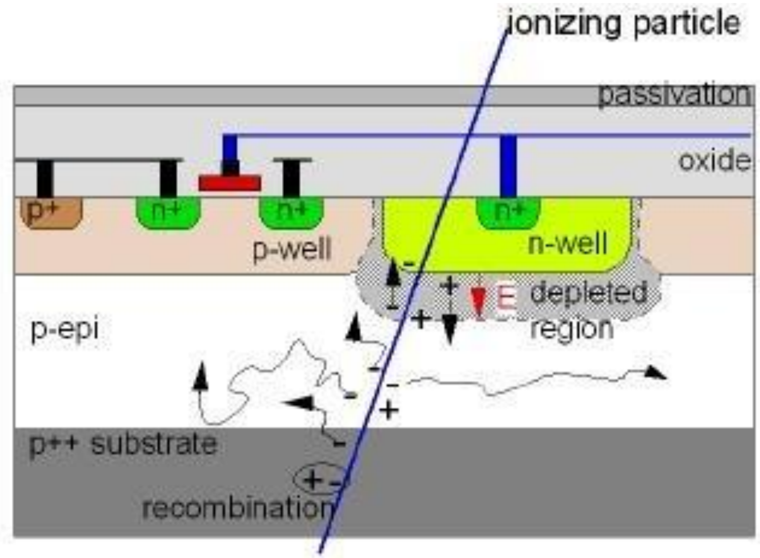
Silicon Vertex: the inner part of a detector



The inner part of the detector is
Essential to identify the particles that decay
immediately after the collision !

Silicon Vertex for a Electron Ion Collider

Vertex system based on Monolithic Active Pixel Silicon Sensor (MAPS)



Tests ongoing at BNL and Columbia University on MAPS Mimosa 26 prototypes designed in Institut Pluridisciplinaire Hubert Curien,Strasbourg.

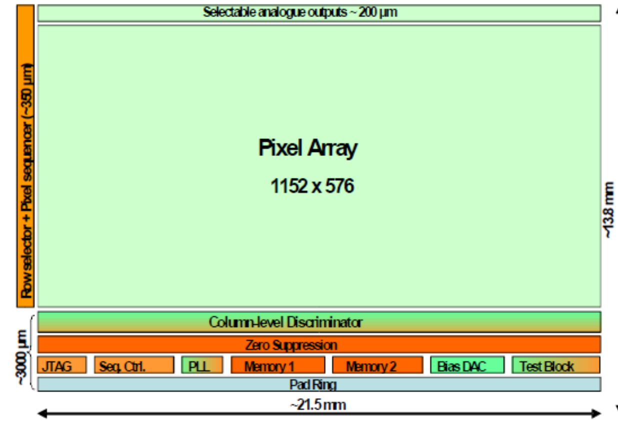
Keypoints:

- ✓ **All the sensor is produced using a standard CMOS technology.**
- ✓ **Works at room temperature: low cooling material budget.**
- ✓ **Low bias voltage required: electrons are collected for thermal diffusion.**
- ✓ **High resolution.**

Silicon Vertex

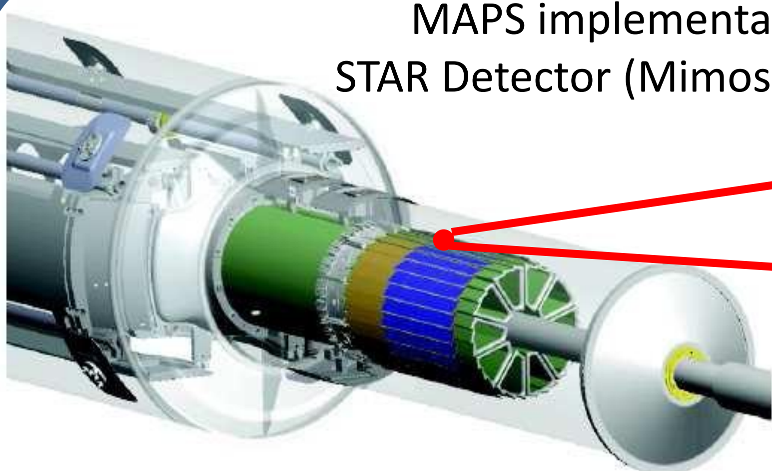
Mimosa 26 :

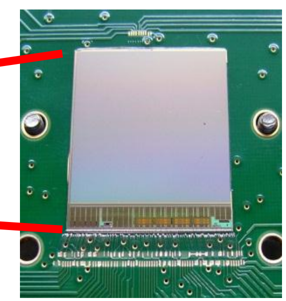
- ✓ Matrix of 663 552 pixels: 576 lines x 1152 col.
- ✓ 13.7 mm X 21.5 mm Matrix Surface
- ✓ Pitch= 18 μm
- ✓ Sensitive volume thickness 15 μm
- ✓ Digital data stream after zero suppression



See for details: http://www.iphc.cnrs.fr/List-of-MIMOSA-chips.html

MAPS implementation in the
STAR Detector (Mimosa 28 Ultimate)





https://indico.bnl.gov/getFile.py/access?contribId=30&resId=0&materialId=slides&confId=521dd

Conclusions

- **The Physics case for e/A collider is well established:**
  with this machine we can answer to a lot of question still open in Nucleon/ Nucleus structure.
- **The design for a electron/Ion collider and a new detector in BNL is in good shape.**
- **A lot of research is ongoing in order to find new and original solutions for the new facility.**

Thanks for your attention !

Other links

- EIC White Paper

http://skipper.physics.sunysb.edu/~abhay/eicwp12/Main.html

- Call for EIC proposal

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

- **eRHIC BNL home page**

https://wiki.bnl.gov/eic/index.php/Main_Page

- **eRHIC BNL Collider Accelerator Department**

http://www.bnl.gov/cad/eRhic/

- **EIC Montecarlo page**

https://wiki.bnl.gov/eic/index.php/Simulations

- **EIC R&D Simulation workshop (BNL October 8TH -9TH 2012)**

https://wiki.bnl.gov/conferences/index.php/EIC_RD_Simulation/Agenda

- **Gluons and quark sea at high energies:**

Report on a ten week program that toke place at the Institute for Nuclear Theory (Seattle, Fall 2010)
http://:arxiv/abs/1108.1713

Other talks on eRHIC in the
2012 Fall Meeting of the APS Division of Nuclear Physics

http://meeting.aps.org/Meeting/DNP12/sessionindex2

- **Mattew Lamont** (Brookhaven National Laboratory)

Measuring the gluon distribution of nuclei: diffractive e+A collisions at eRHIC
Session DE: Heavy Ions; 11:42 AM–11:54 AM, Thursday, October 25, 2012

- **Aidala Cristina** (University of Michigan)

Entering the Electronic Age at RHIC: eRHIC
Session 1WB: Hadron Physics IV;10:00 AM–10:30 AM,Friday, October 26, 2012

- **Thomas Burton** (Brookhaven National Laboratory)

eRHIC as a Nucleon Tomograph
Session PE: Hadron Physics IV; 11:42 AM–11:54 AM, Saturday, October 27, 2012

- **Liang Zheng** (Brookhaven National Laboratory)

Dihadron Correlation in the eA program at an Electron Ion Collider
Session PE: Hadron Physics IV; 11:30 AM–11:42 AM, Saturday, October 27, 2012

- **Benedetto Di Ruzza** (Brookhaven National Laboratory)

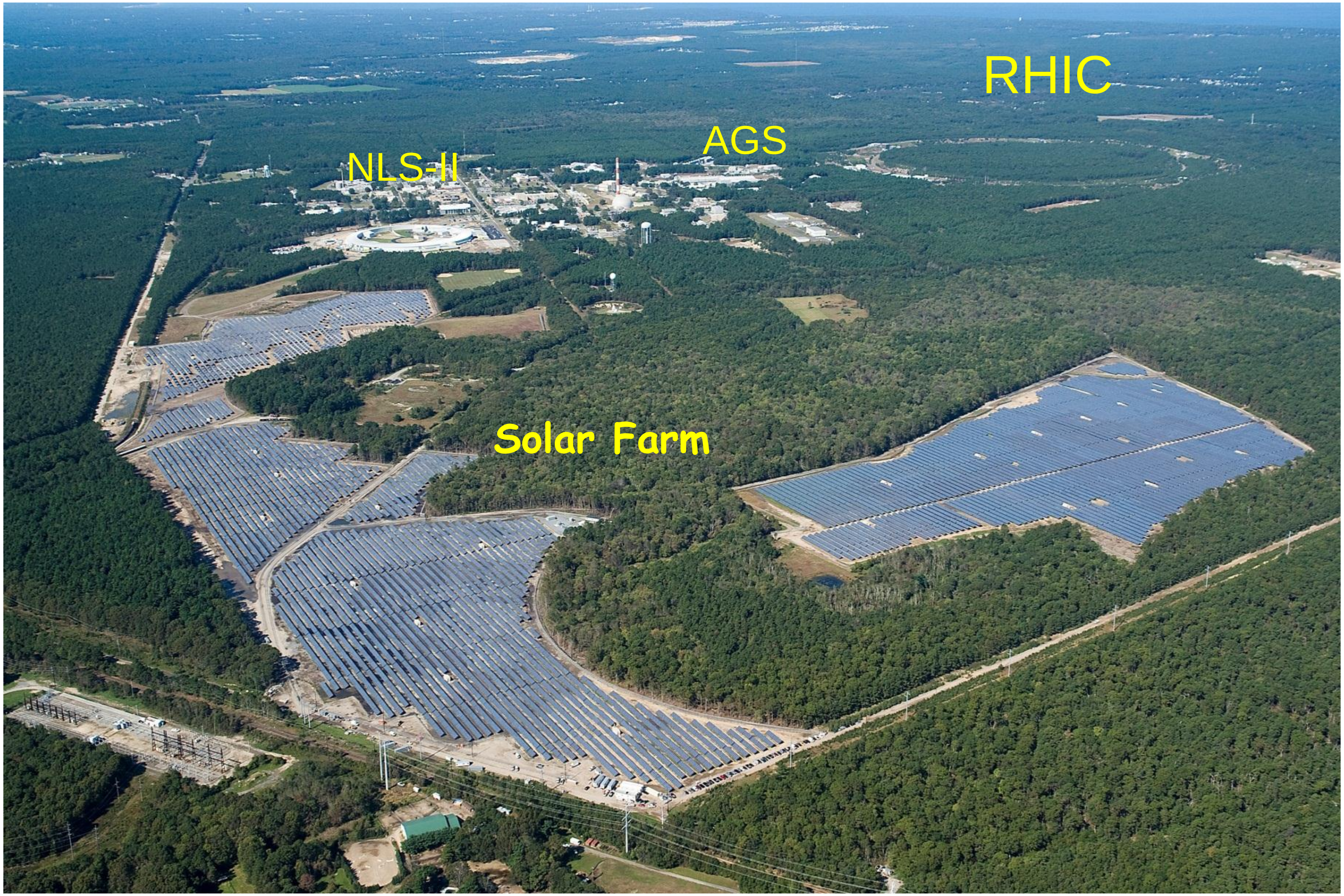
The eRHIC Detector: Design and Realization
Session PC: instrumentation IV; 11:18 AM–11:30 AM, Saturday, October 27, 2012

Acknowledgment

Thanks to the members of the BNL collider Accelerator Department and the BNL EIC Science task Force for the material provided, for useful discussions, and for the profound suggestions.
This work was supported by the BNL LDRD program.

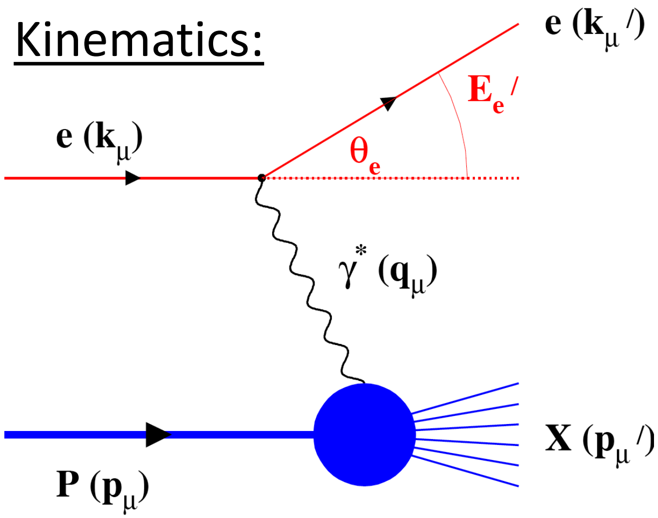
BACK-UP Slides

Brookhaven National Laboratory



How to see the gluons: Deep Inelastic Scattering

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e(1-\cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

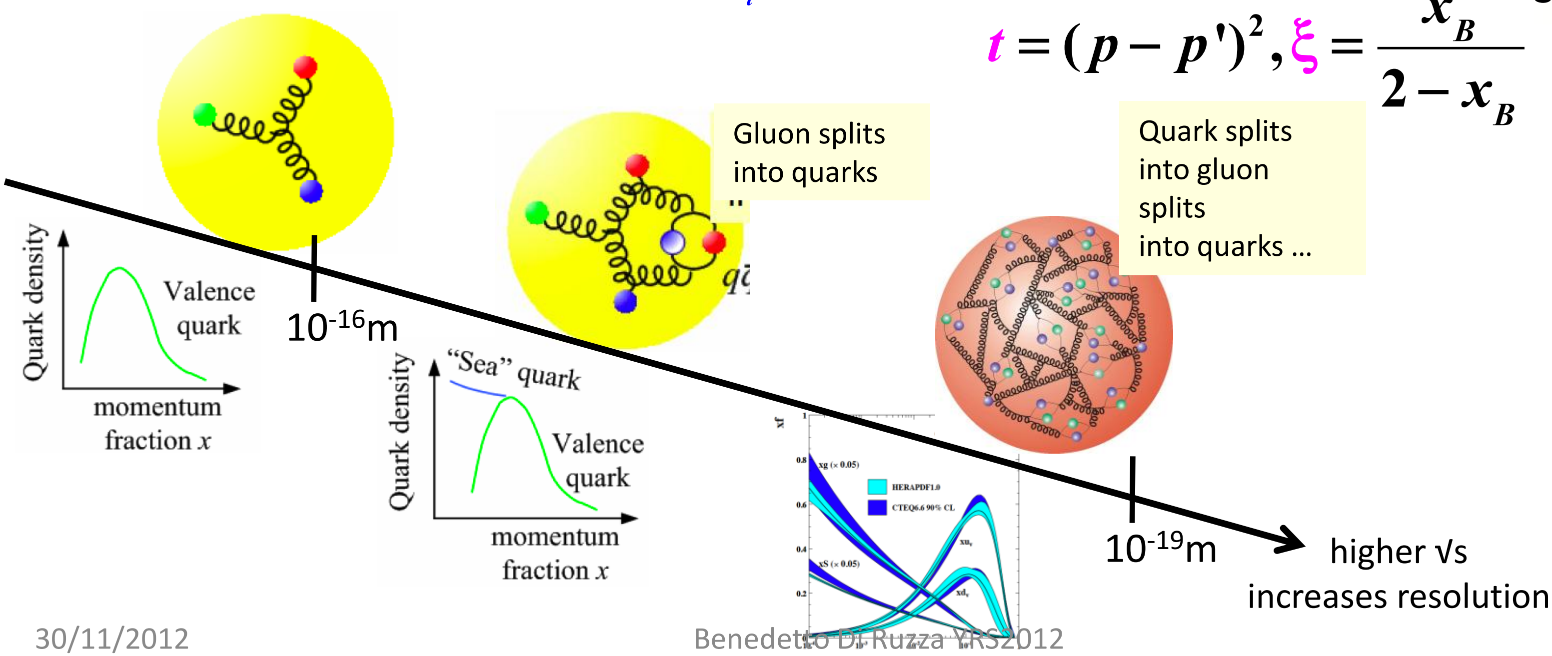
$$Hadron: z = \frac{E_h}{\nu};$$

$$x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

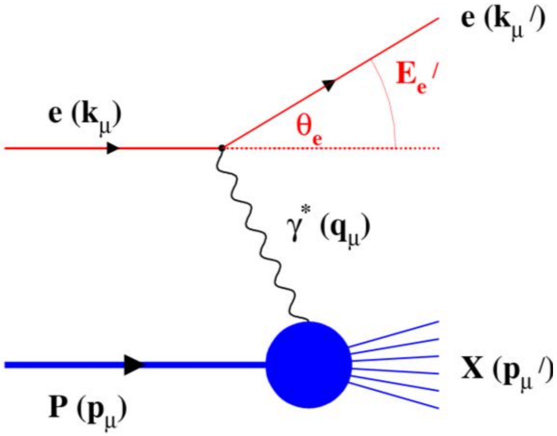
Measure of momentum fraction of struck quark

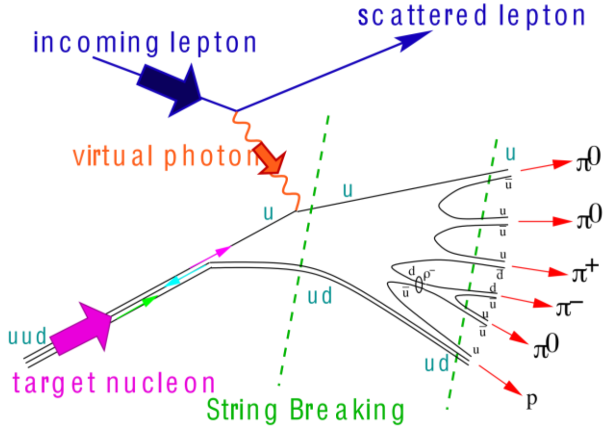
p_t^h: with respect to γ^*

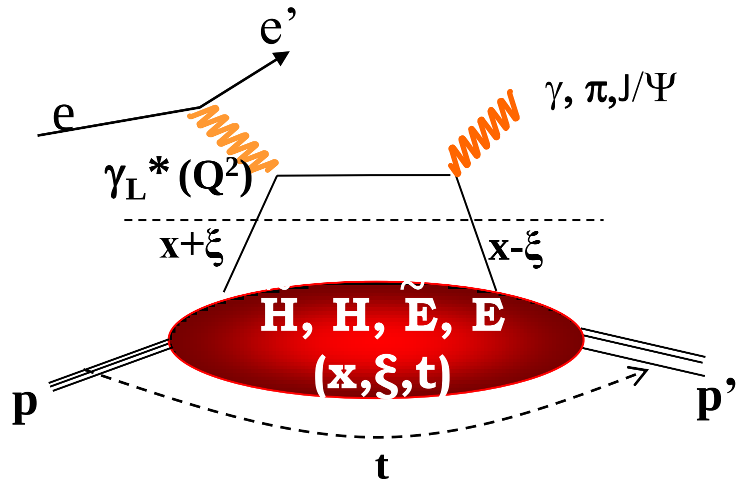
$$t = (p-p')^2, \xi = \frac{x_B}{2-x_B}$$



What needs to be covered







Inclusive Reactions:

- Momentum/energy and angular resolution of e' critical
- Very good electron id
- Moderate luminosity $>10^{32}$ cm^{-1} s^{-1}
- Need low x ~10^{-4} → high √s (Saturation and spin physics)

Semi-inclusive Reactions:

- Excellent particle ID: π,K,p separation over a wide range in η
- full Φ-coverage around γ*
- Excellent vertex resolution → Charm, bottom identification
- high luminosity $>10^{33}$ cm^{-1} s^{-1} (5d binning (x,Q^2,z,p_t,Φ))
- Need low x ~10^{-4} → high √s

Exclusive Reactions:

- Exclusivity → high rapidity coverage → rapidity gap events
- high resolution in t → Roman pots
- high luminosity $>10^{33}$ cm^{-1} s^{-1} (4d binning (x,Q^2,t,Φ))

eRHIC Collider parameters

	e	p	$^{3}_{2}He$	$^{197}_{79}Au$	$^{238}_{92}U$
Energy, GeV	10	250	167	100	100
CM energy, GeV		100	82	63	63
Number of bunches/distance between bunches	107 nsec	111	111	111	111
Bunch intensity (nucleons)	$0.24 \cdot 10^{11}$	$4 \cdot 10^{11}$	$6 \cdot 10^{11}$	$6 \cdot 10^{11}$	$6.3 \cdot 10^{11}$
Bunch charge, nC	5.8	64	60	39	40
Beam current, A	0.05	0.556	0.556	0.335	0.338
Normalized emittance of hadrons 95% , mm mrad		1.2	1.2	1.2	1.2
Normalized emittance of electrons, rms, mm mrad		16	24	40	40
Polarization, %	80	70	70	none	none
RMS bunch length, cm	0.2	5	5	5	5
β*, cm	5	5	5	5	5
Luminosity per nucleon, $cm^{-2} s^{-1}$		**2.7×10^{34}**	**2.7×10^{34}**	**1.6×10^{34}**	**1.7×10^{34}**

Overview of the New Detector

- Si-Vertex
  - MAPS technology from IPHC ala STAR, CBM, Alice, …)
    - Barrel:

    4 double sided layers @ 3. 5.5 8. 15. cm 10 sectors in Φ
    - Forward Disks:

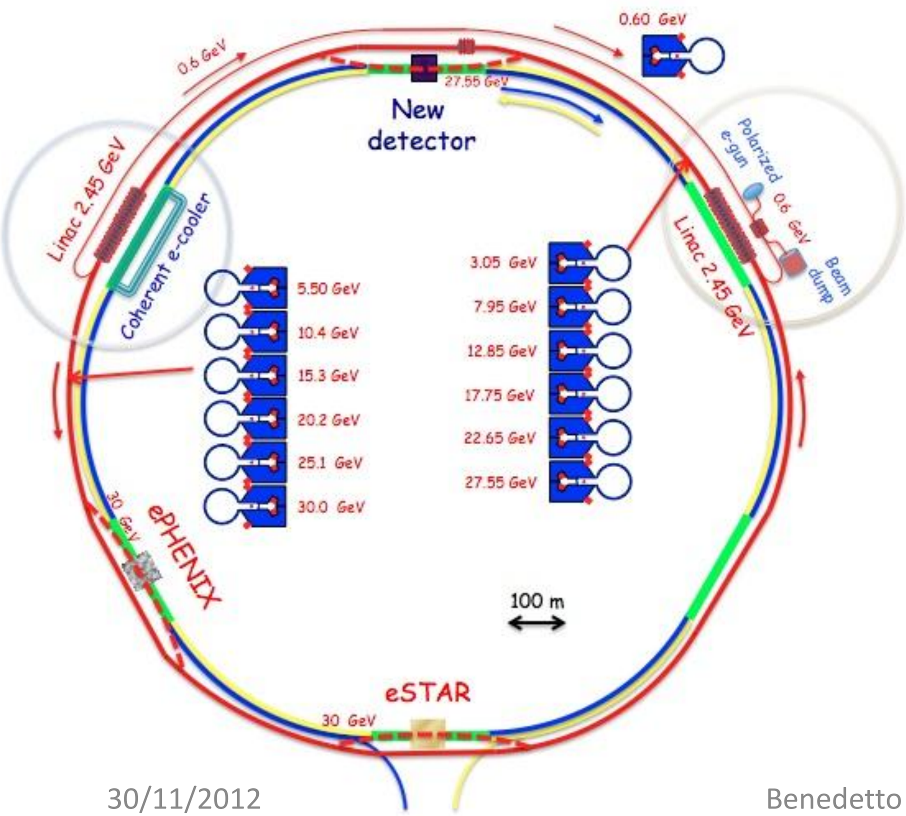
    4 single sided disks spaced in z starting from 20 cm, dual sided readout ?
- Barrel Tracking
  - Preferred technology TPC (alternative GEM-Barrel tracker Mass?)
    - Low mass, PID e/h via dE/dx
- Forward tracking
  - GEM-Trackers
- Forward/Backward RICH-Detectors
  - Momenta to be covered: 0.5-80 GeV for $1<|y|<4(5)$
  - Technology:
    - Dual Radiator (HERMES, LHCb) Aerogel+Gas (C_4F_{10} or C_4F_8O)
  - Photondetector: low sensitivity to magnetic field

Overview of the New Detector

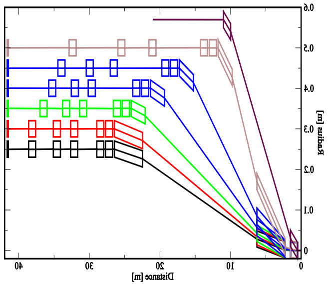
- Barrel PID-Detectors
  - Momenta to be covered 0.5-10 GeV for $-1<y<1$
  - Technology:
    - Aerogel Proximity focusing RICH
    - DIRC
- ECal:
  - Backward/Barrel:
    - PbW-crystal calorimeter $\rightarrow$ great resolution, small Molière radius $\rightarrow$ electron-ID: e/p, measure lepton via Ecal, important for DVCS
  - Forward:
    - Less demanding: sampling calorimeter
- Preshower
  - Si-W technology as proosed for PHENIX MPCEX
- Hcal/Muons-Detectors
  - Not obvious they are really needed
- Luminosity monitor, electron and hadron polarimeters

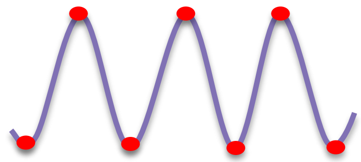
Accelerator complex

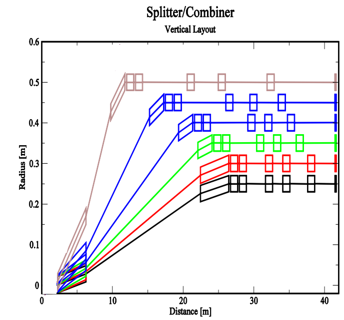
- ✓ **Electrons beam: new High Energy ERL**
- ✓ **Protons beam: new coherent electron cooling**
- ✓ **Crab Crossing Cavities to restore Head to head bunches collisions**

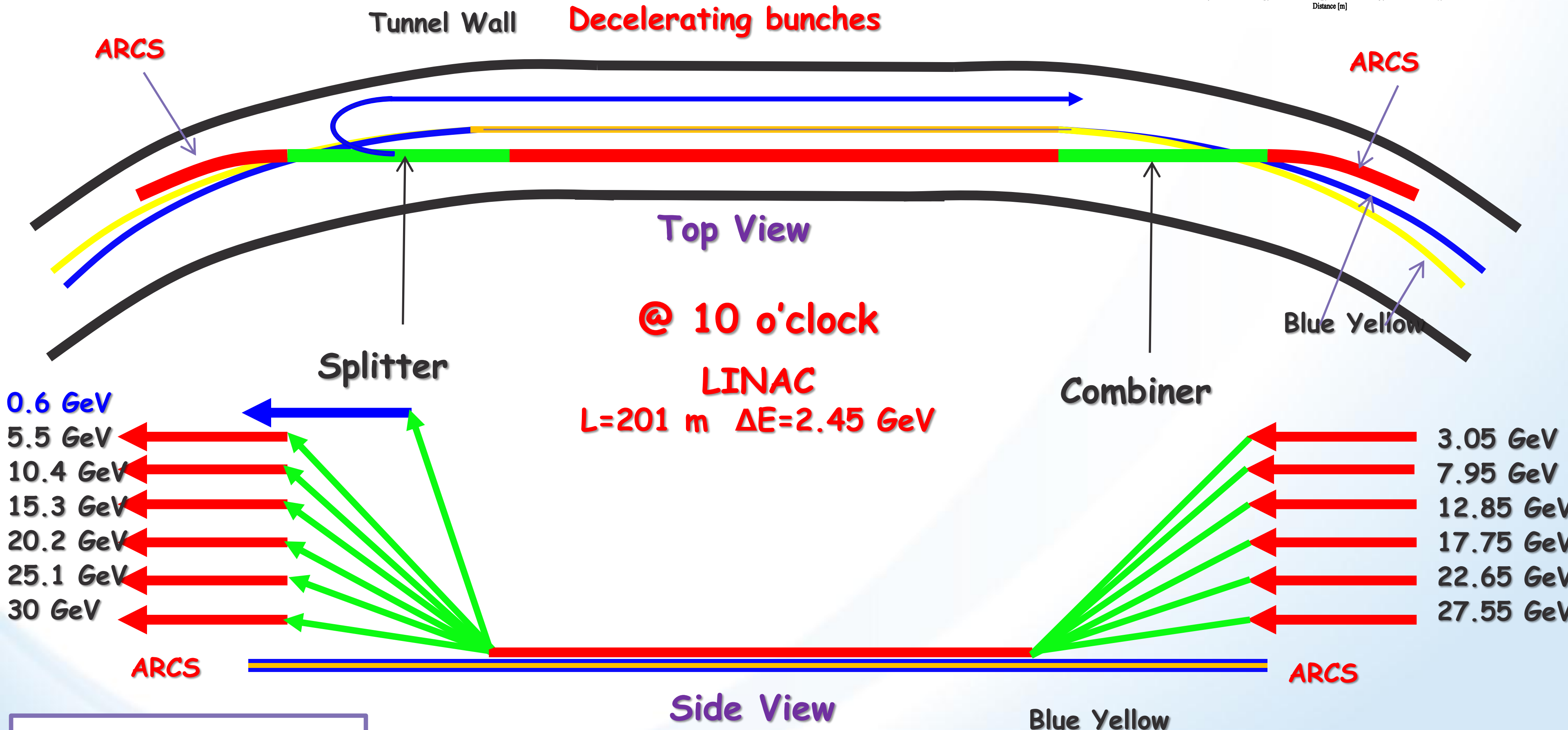


SPLITTER/COMBINER/LINAC









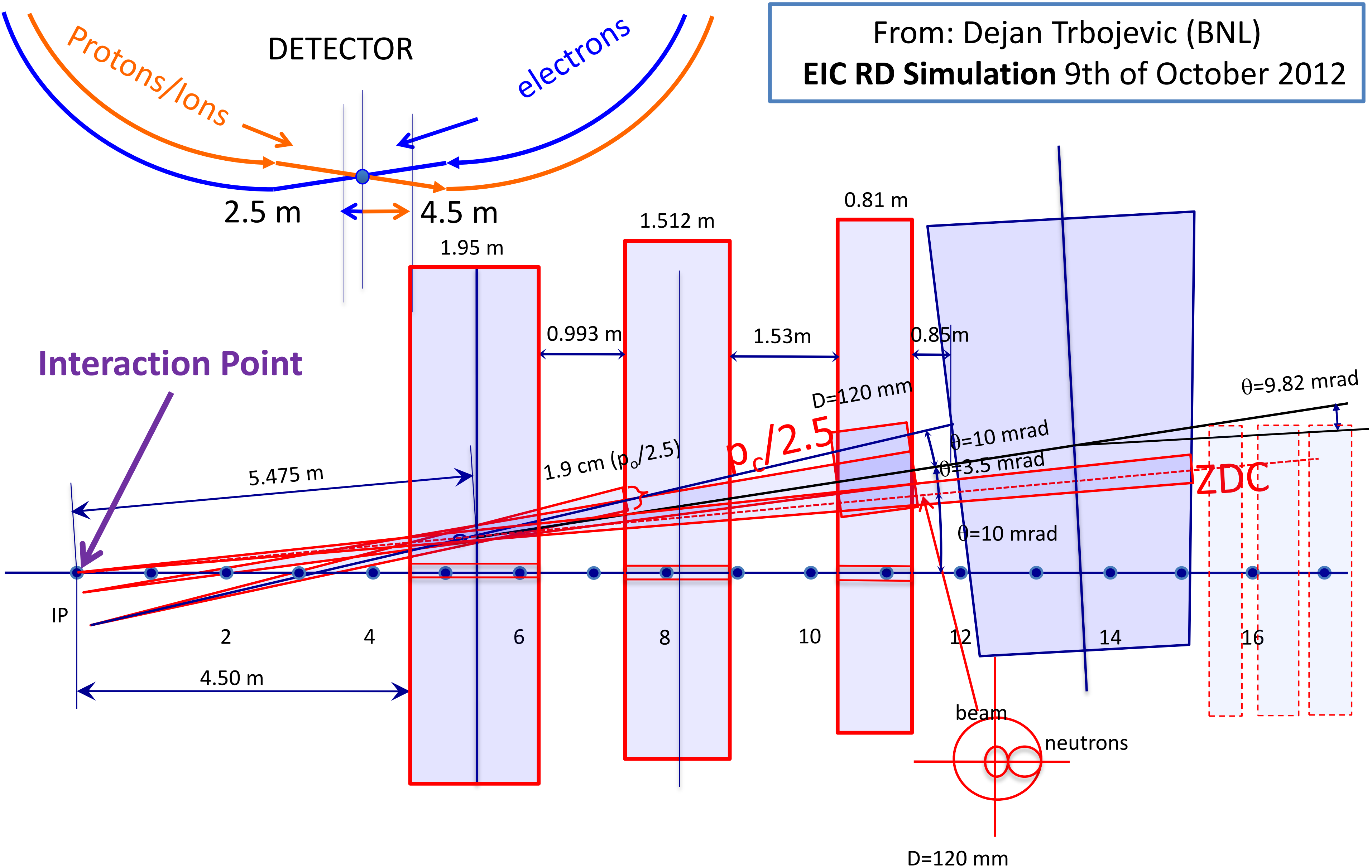
Vladimir Litvinenko (BNL)

Brookhaven Lecture

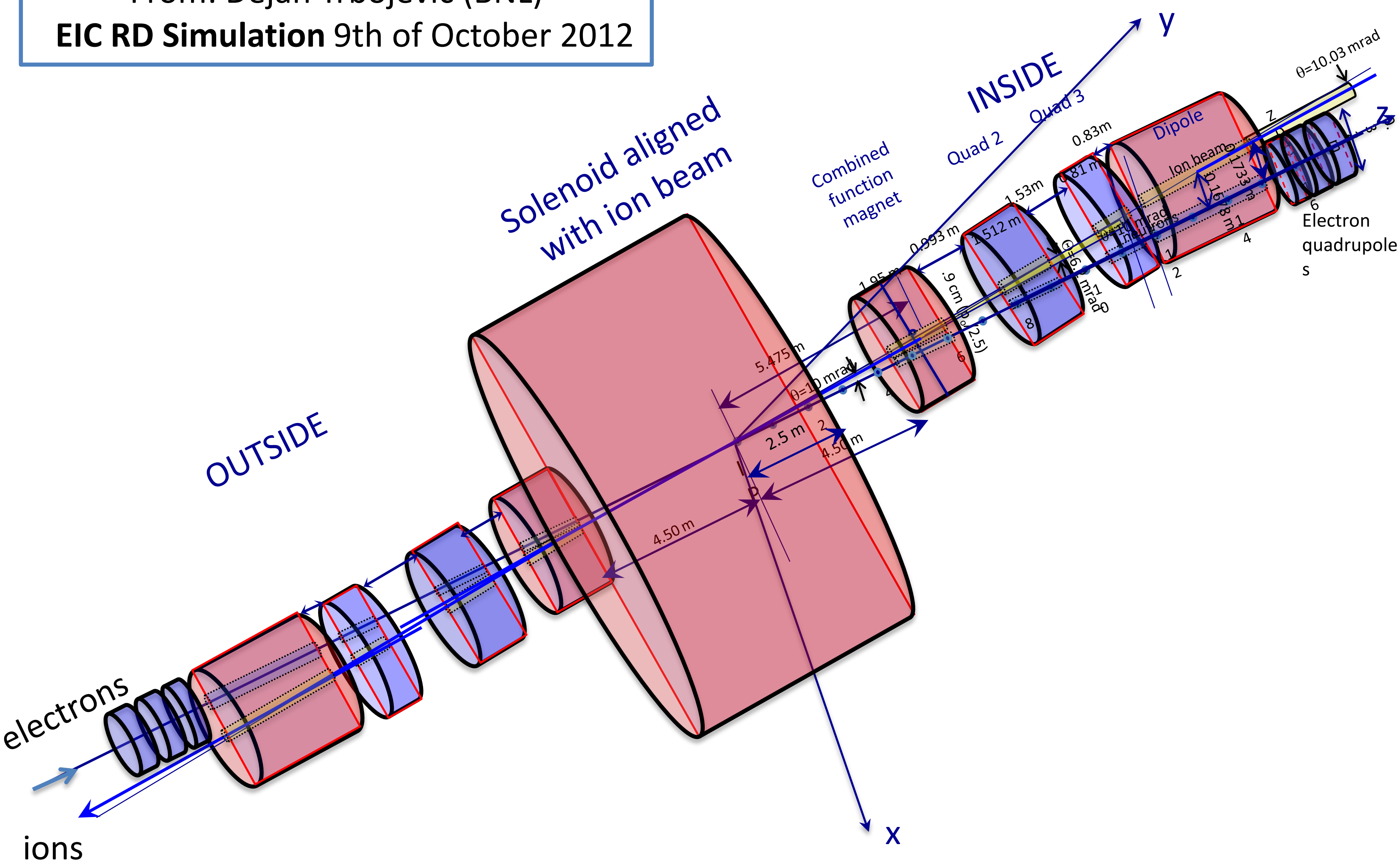
14th of November 2012

IP configuration for eRHIC

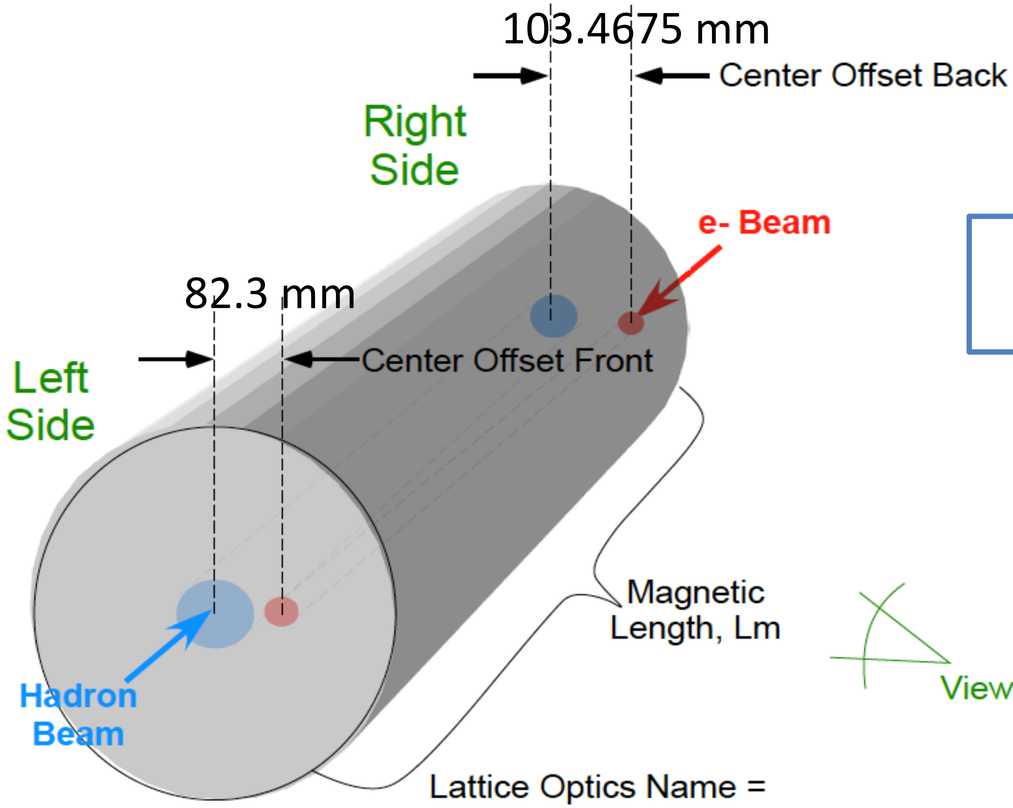
From: Dejan Trbojevic (BNL)
EIC RD Simulation 9th of October 2012



From: Dejan Trbojevic (BNL)
EIC RD Simulation 9th of October 2012



Q2

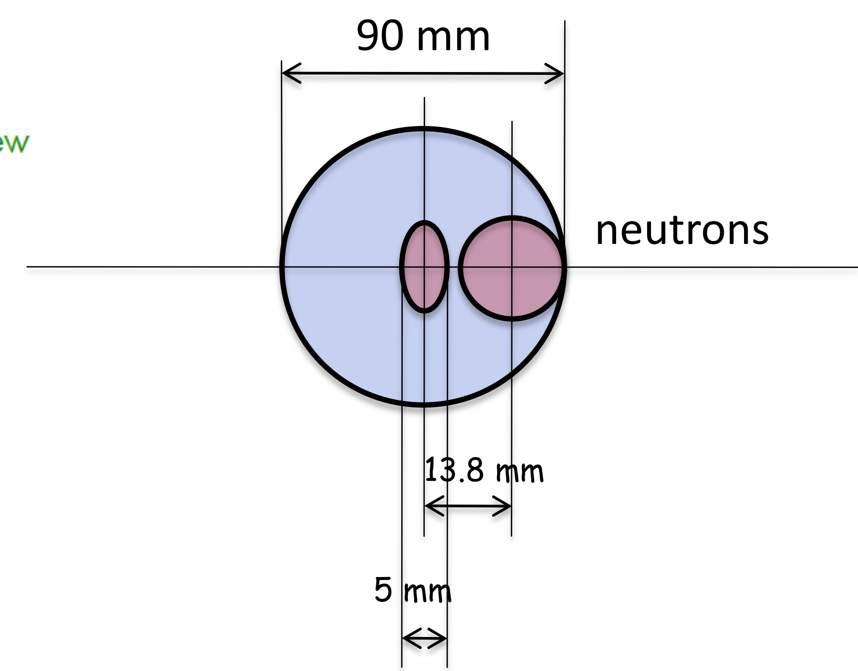


From: Dejan Trbojevic (BNL)
EIC RD Simulation 9th of October 2012

Lattice Optics Name =	
IR Location (Right/Left) =	Q2
Magnetic Length (m) =	left
Gradient (T/m) =	1.5157 m
Residual Field at e-Beam axis (Gauss) =	200 T/m
Hadron Beam Clear Bore Diameter (mm) =	1 G
Electron Beam Clear Bore Diameter (mm) =	90 mm
E-beam Center Offset Front (mm) =	18 mm
E-Beam Center Offset Back (mm) =	82.3 mm
	103.4675 mm

Name & Date filled Out ____________________

Hadron Aperture Q_2

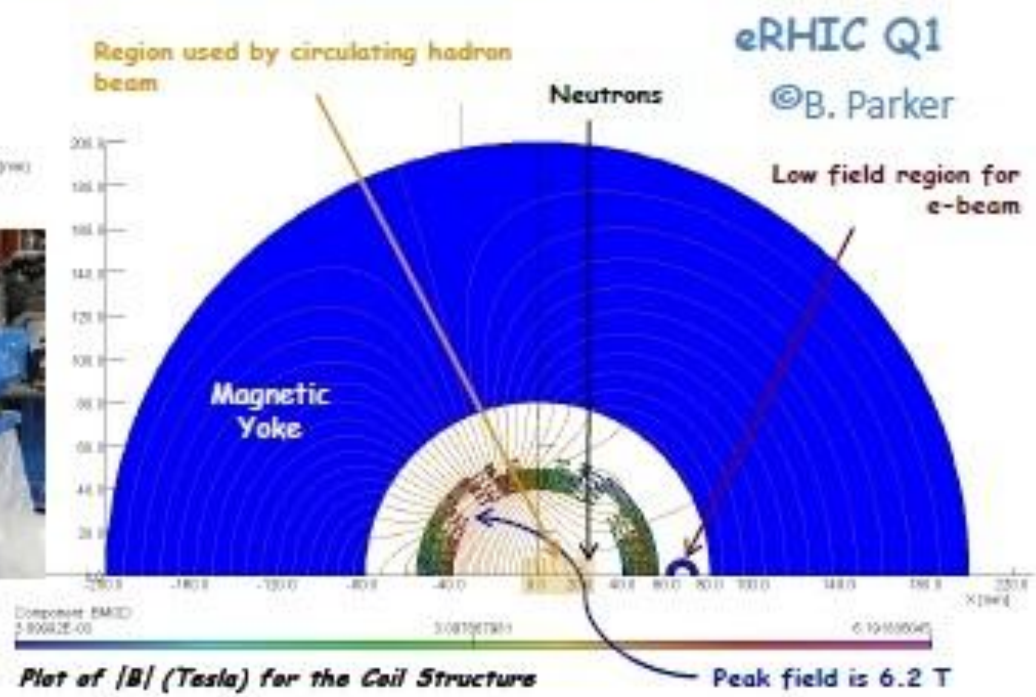


6•σ=6 •√ 916m1.2/6265.76=5 mm

The special IR magnet

- Large aperture for passage of neutrons and gammas, circulating beam and off-momentum charged particle.
- Based on Nb_3Sn magnet technology developed for LHC IR upgrade

LHC IR magnet prototype



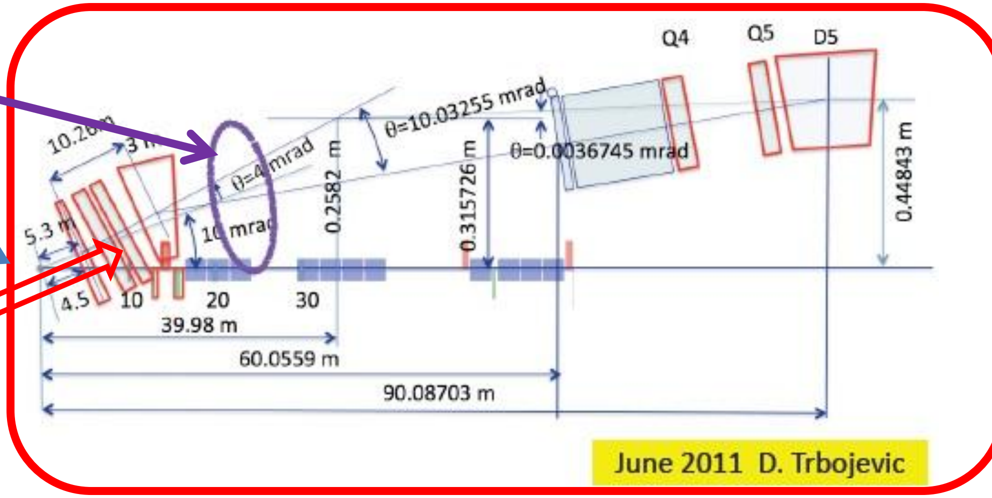
From: Y.Hao on behalf of eRHIC design team 2012 RHIC & AGS Annual User's Meeting

Roman Pots Studies

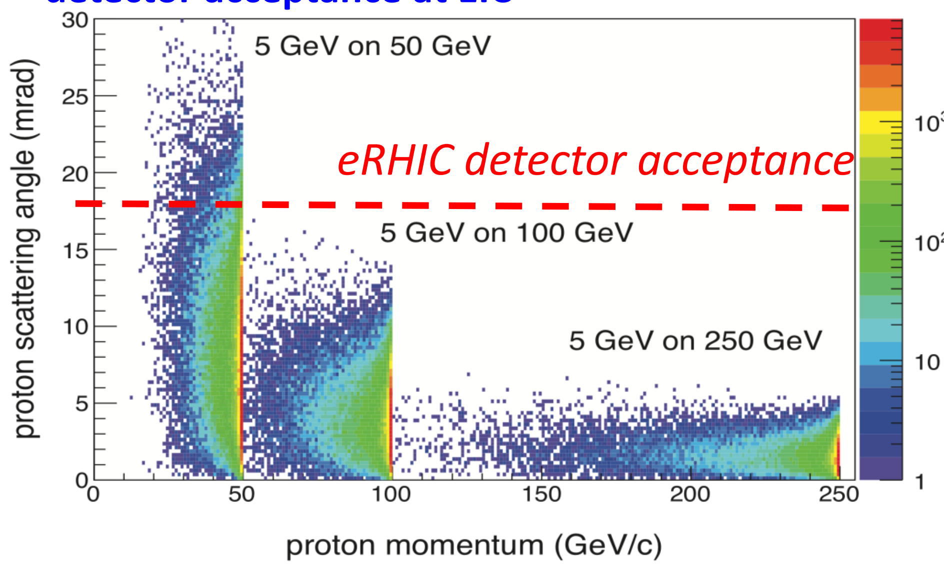
Roman Pots station
(20 – 22 m from IP)

Interaction Point

Hadron Beam Direction

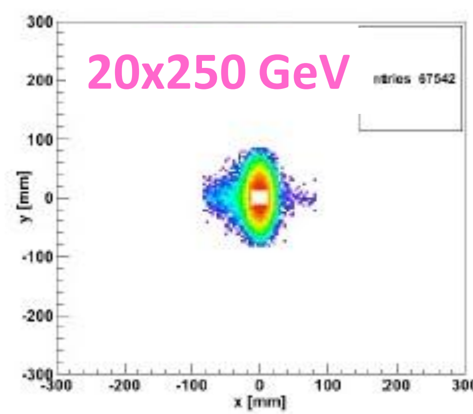


leading protons are never in the main detector acceptance at EIC



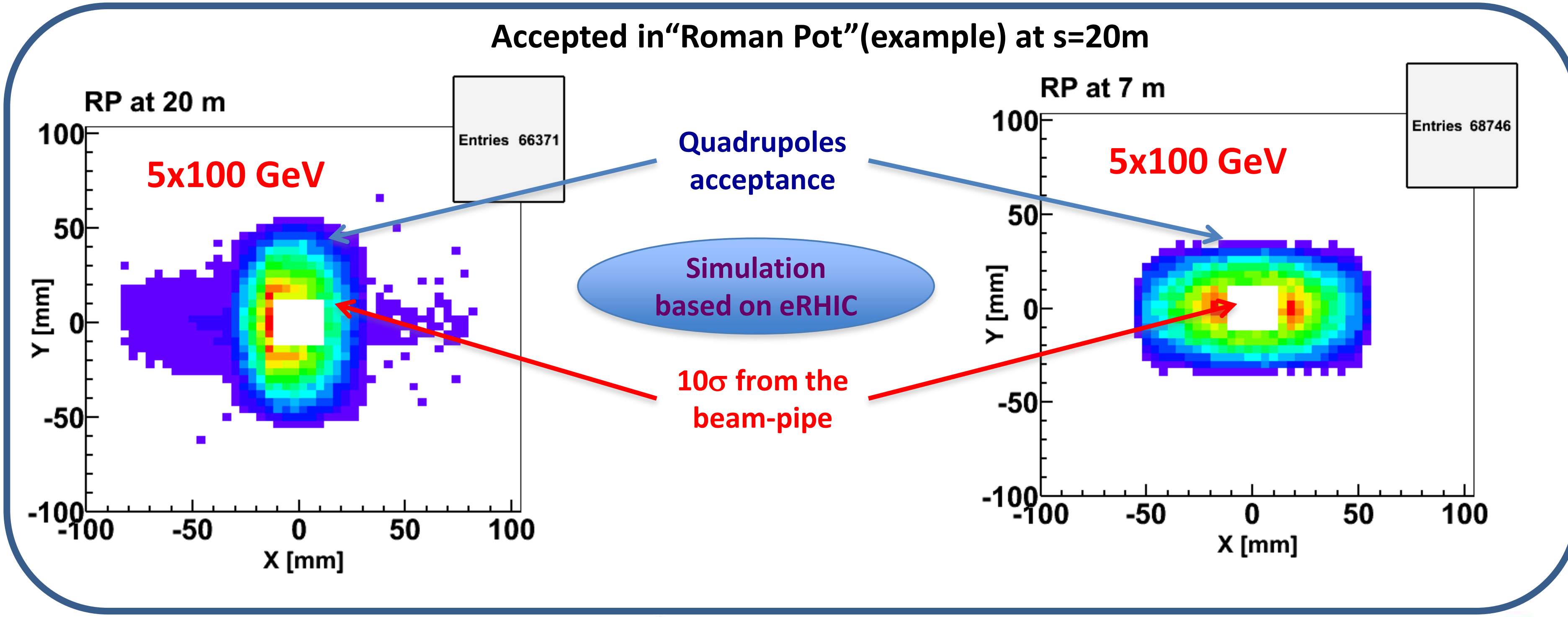
Main detector

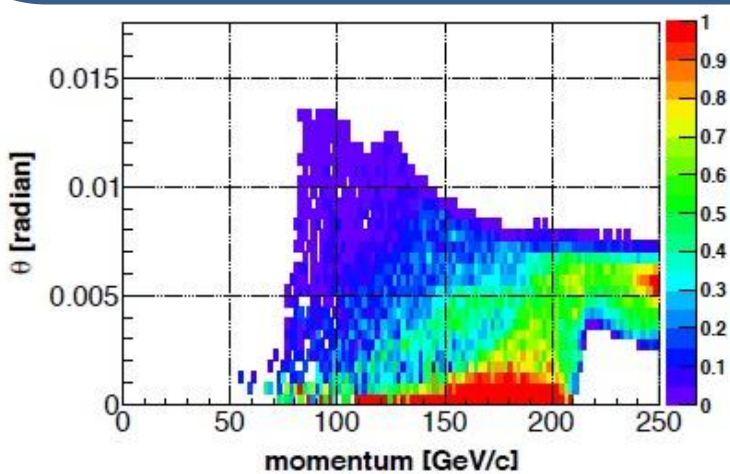
Roman Pots

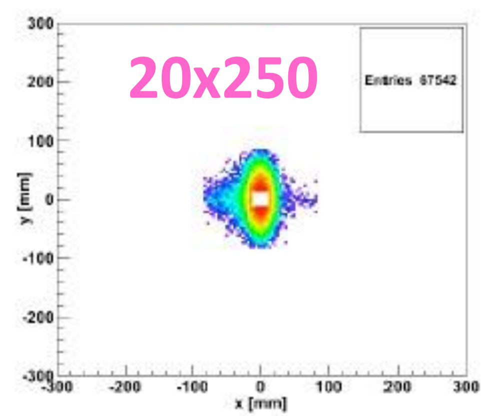


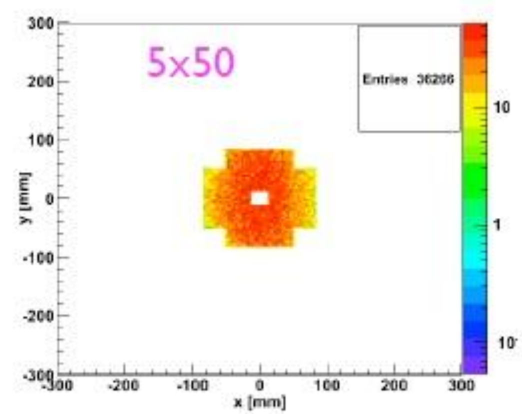
Plots from J-H Lee

Roman Pots Studies







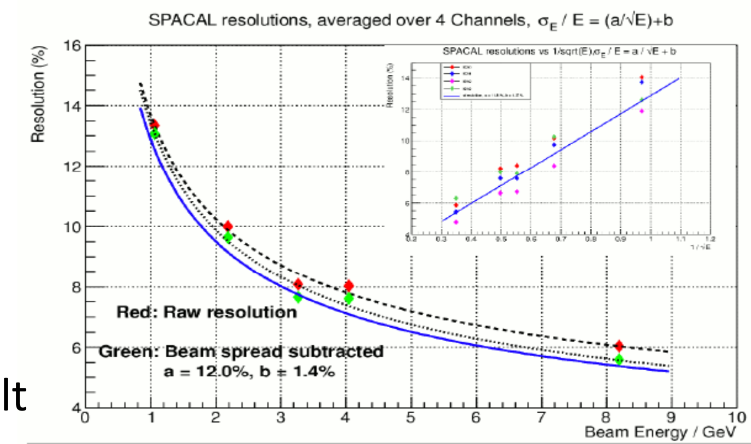


Calorimeters

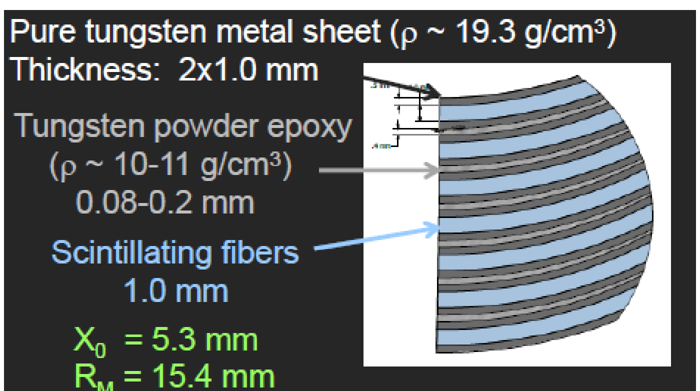
New technologies under consideration:

STAR Forward Calorimeter:Tungsten Powder/Epoxy/SciFi

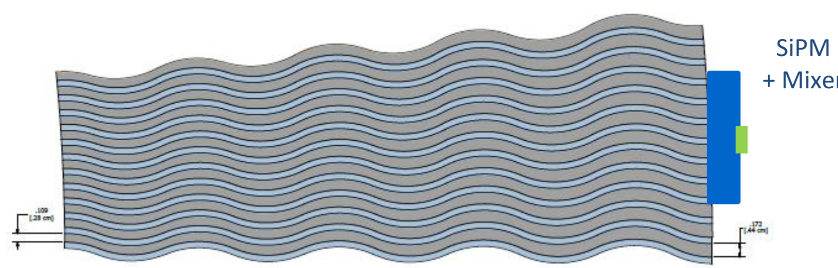
O. Tsai, H. Huang (UCLA)



Fermilab Test Beam result



Tungsten-Scintillating Fiber
"Optical Accordion" EM Calorimeter



Tracking System